PRINCIPLES OF MANURING

MANURES

AND THE

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BY

C. M. AIKMAN, M.A., B.Sc., F.R.S.E., F.I.C.

PROFESSOR OF CHEMISTRY, GLASGOW VETERINARY COLLEGE;
EXAMINER IN CHEMISTRY, GLASGOW UNIVERSITY;
AUTHOR OF 'FARMYARD MANURE,' ETC.

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Agriculture Dept

TO

SIR JOHN BENNET LAWES, BART., D.C.L., LL.D., F.R.S.,

OF ROTHAMSTED,

AND

SIR J. HENRY GILBERT, M.A., LL.D., F.R.S.,

FORMERLY SIBTHORPIAN PROFESSOR OF RURAL ECONOMY,

UNIVERSITY OF OXFORD,

WHOSE FAMOUS INVESTIGATIONS DURING THE LAST FIFTY YEARS

HAVE SO LARGELY CONTRIBUTED TO BUILD UP

THE SCIENCE OF MANURING,

THIS WORK,

EMBODYING MANY OF THE ROTHAMSTED RESULTS,

IS DEDICATED.

PREFACE.

WHEN the present work was first undertaken there were but few works in English dealing with its subject-matter, and hardly any which dealt with the question of Manuring at any length. During the last few years, however, owing to the greatly increased interest taken in agricultural education, the demand for agricultural scientific literature has called into existence quite a number of new works. Despite this fact, the author ventures to believe that the gap which the present treatise was originally designed to fill is still unfilled.

Of the importance of the subject all interested in agriculture are well aware. It is no exaggeration to say that the introduction of the practice of artificial manuring has revolutionised modern husbandry. Indeed, without the aid of artificial manures, arable farming, as at present carried out, would be impos-

sible. Fifty years ago the practice may be said to have been unknown; yet so widespread has it now become, that at the present time the capital invested in the manure trade in this country alone amounts to millions sterling. It need scarcely be pointed out, therefore, that a practice in which such vast monetary interests are involved is worthy of the most careful consideration by all students of agricultural science, as well as, it may be added, by political economists.

The aim of the present work is to supply in a concise and popular form the chief results of recent agricultural research on the question of soil fertility, and the nature and action of various manures. It makes no pretence to be an exhaustive treatise on the subject, and only contains those facts which seem to the author to have an important bearing on agricultural practice. In the treatment of its subject it may be said to stand midway between Professor Storer's recently published elaborate and excellent treatise on 'Agriculture in some of its Relations to Chemistry'—a work which is to be warmly recommended to all students of agricultural science, and to which the author would take this opportunity of acknowledging his indebtedness—and Dr J. M. H. Munro's admirable little work on 'Soils and Manures.'

In order to render the work as intelligible to the ordinary agricultural reader as possible, all tabular matter and matter of a more or less technical nature

have been relegated to the Appendices attached to each chapter.

The author's somewhat wide experience as a University Extension Lecturer, and as a Lecturer in connection with County Council schemes of agricultural education, during the last few years, induces him to believe that the work may be of especial value to those engaged in teaching agricultural science.

He has to express the deep obligation he is under, in common with all writers on Agricultural Chemistry, to the classic researches of Sir John Bennet Lawes, Bart., and Sir J. Henry Gilbert, now in progress for more than fifty years at Sir John Lawes' Experiment Station at Rothamsted. His debt of gratitude to these distinguished investigators has been still further increased by their kindness in permitting him to dedicate the work to them, and for having been good enough to read portions of the work in proof. In addition to the free use which has been made throughout the book of the results of these experiments, the last chapter contains, in a tabular form, a short epitome of some of the more important Rothamsted researches on the action of different manures.

To the numerous German and French works on the subject, more especially to Professor Heiden's encyclopædic 'Lehrbuch der Düngerlehre' and the various writings of Dr Emil von Wolff, the author is further much indebted.

Among English works he would especially mention the assistance he has derived from the writings of Mr R. Warington, F.R.S., Professor S. W. Johnson, Professor Armsby, the late Dr Augustus Voelcker, and others. He would also tender his acknowledgments to the new edition of Stephens' 'Book of the Farm,' and he has to thank its editor, his friend Mr James Macdonald, Secretary to the Highland and Agricultural Society of Scotland, for having read parts of his proof-sheets.

It is also his pleasing duty to thank his friends Dr Bernard Dyer, Hon. Secretary of the Society of Public Analysts; Dr A. P. Aitken, Chemist to the Highland and Agricultural Society of Scotland; Professor Douglas Gilchrist of Bangor; Mr F. J. Cooke, late of Flitcham; Mr Hermann Voss of London; and Professor Wright of Glasgow, for having assisted him in the revision of proof-sheets.

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PART I.

HISTORICAL INTRODUCTION

MANURES AND THE PRINCIPLES OF MANURING.

HISTORICAL INTRODUCTION.

Agricultural Chemistry, like most branches of natural science, may be said to be entirely of modern growth. While it is true we have many old speculations on the subject, they can scarcely be said to possess much scientific value. The great questions which had first to be solved by the agricultural chemist were,—What is the food of plants? and,—What is the source of that food? The second of these two questions more easily admitted of answer than the first. The source of plant-food could only be the atmosphere or the soil. As the composition of the atmosphere, however, was not discovered till the close of last century, and the chemistry of the soil is a question which is still requiring much work

ere we shall be in possession of anything like a full knowledge of it, it will be at once obvious that the very fundamental conditions for a solution of the question were awanting. The beginning, then, of a true scientific agricultural chemistry may be said to date from the brilliant discoveries associated with the names of Priestley, Scheele, Lavoisier, Cavendish, and Black—that is, towards the close of last century.

Early Theories on Source of Plant-food.

While this is so, and while we must regard the early attempts made towards solving this question as being, for the most part, of little scientific value, it is not without interest, from the historical point of view, to glance briefly at some of these old interesting speculations.

The Aristotelian doctrine, regarding the possibility of dividing matter into the so-called four primary elements, *fire*, *air*, *earth*, and *water*, which obtained in one form or another till the birth of modern chemistry, had naturally an important influence on these early theories.

Van Helmont's Theory.

Among the earliest and most important attempts made to solve the problem of plant-growth was that by Jean Baptiste Van Helmont, one of the best known of the alchemists, who flourished about the beginning of the seventeenth century. Van Helmont believed

that he had proved by a conclusive experiment that all the products of vegetables were capable of being generated from water. The details of this classical experiment were as follows:—

"He took a given weight of dry soil—200 lb.—and into this soil he planted a willow-tree that weighed 5 lb., and he watered this carefully from time to time with pure rain-water, taking care to prevent any dust or dirt falling on to the earth in which the plant grew. He allowed this to go on growing for five years, and at the end of that period, thinking his experiment had been conducted sufficiently long, he pulled up his tree by the roots, shook all the earth off, dried the earth again, weighed the earth and weighed the plant. He found that the plant now weighed 169 lb. 3 ounces, whereas the weight of the soil remained very nearly what it was—about 200 lb. It had only lost 2 ounces in weight." [1]

The conclusion, therefore, come to by Van Helmont was that the source of plant-food was *water*.[2]

[1] The History of the Chemical Elements. By Sir Henry E. Roscoe, F.R.S. (Wm. Collins, Sons, & Co.)

[2] Van Helmont's science was, however, of an extremely rudimentary nature, as may be evidenced by the belief he entertained that the smells which arise from the bottom of morasses produce frogs, slugs, leeches, and other things; as well as by the following recipe which he gave for the production of a pot of mice: "Press a dirty shirt into the orifice of a vessel containing a little corn, after about twenty-one days the ferment proceeding from the dirty shirt, modified by the odour of the corn, effects a transmutation of the wheat into mice." The crowning point in this recipe, however, lay in the fact that he

Digby's Theory.

Some fifty years later an extremely interesting book was published bearing the following title: 'A Discourse concerning the Vegetation of Plants, spoken by Sir Kenelm Digby, at Gresham College, on the 23d of January 1660. (At a meeting of the Society for promoting Philosophical Knowledge by Experiments. London: Printed for John Williams, in Little Britain, over against St Botolph's Church, 1669.)' The author attributes plant-growth to the influence of a *balsam* which the air contains. This book is especially interesting as containing the earliest recognition of the value of saltpetre as a manure. The following is an extract from this interesting old work:—

"The sickness, and at last the death of a plant, in its natural course, proceeds from the want of that balsamick saline juice; which, I have said, makes it swell, germinate, and augment itself. This want may proceed either from a destitution of it in the place where the plant grows, as when it is in a barren soil or bad air, or from a defect in the plant itself, that hath not vigour sufficient to attract it, though it be within the sphere of it; as when the root has become

asserted that he had himself witnessed the fact, and, as an interesting and corroborative detail, he added that the mice were born full-grown. See 'Louis Pasteur: His Life and Labours.' By his Son-in-law. Translated by Lady Claud Hamilton. (Longmans, Green, & Co.) P. 89.

so hard, obstructed and cold, as that it hath lost its vegetable functions. Now, both these may be remedy'd, in a great measure, by one and the same physick. . . . The watering of soils with cold hungray springs doth little good; whereas muddy saline waters brought to overflow a piece of ground enrich it much. But above all, well-digested dew makes all plants luxuriate and prosper most. Now what may it be that endues these liquors with such prolifick virtue? The meer water which is common to them all, cannot be it; there must be something else enclosed within it, to which the water serves but for a vehicle. Examine it by spagyric art, and you will find that it is nothing else than a *nitrous salt,* which is dilated in the water. It is this salt which gives fœcundity to all things: and from this salt (rightly understood) not only all vegetables, but also all minerals draw their origine. By the help of plain *salt-peter,* dilated in water and mingled with some other fit earthy substance, that may familiarize it a little with the corn into which I endeavoured to introduce it, I have made the barrenest ground far out-go the richest, in giving a prodigiously plentiful harvest. I have seen hemp-seed soaked in this liquor, that hath in due time made such plants arise, as, for the tallness and hardness of them, seemed rather to be coppice-wood of fourteen years' growth at least, than plain hemp. The fathers of the Christian doctrine at Paris still keep by them for a monument (and indeed it is an admirable one)

a plant of barley consisting of 249 stalks, springing from one root or grain of barley; in which they counted above 18,000 grains or seeds of barley. But do you think that it is barely the salt-peter, imbibed into the seed or root, which causeth this fertility? no: that would be soon exhausted and could not furnish matter to so vast a progeny. The salt-peter there is like a magnet, which attracts a like salt which fœcundates the air, and gave cause to the Cosmopolite to say there is in the air a hidden food of life."[1]

Duhamel and Hales.

The names of the French writer, Duhamel, and of the English, Stephen Hales, may be mentioned in passing as authors of works bearing on the question of vegetable physiology. Both of these writers flourished about the middle of the eighteenth century. The writings of the former contained much valuable information on the effects of grafting, motion of sap, and influence of light on vegetable growth, and also the results of experiments which the author had carried out on the influence of treating plants with certain substances. 'Statical Essays, containing Vegetable Staticks; or an Account of some Statical Experiments on the Sap of Vegetables, by Stephen Hales, D.D.' (2

[1] He then goes on to relate a number of experiments by Cornelius Drebel and Albertus Magnus, showing the refreshing power of this balsam, and then those of Quercitan with roses and other flowers, and his own with nettles.

vols.), was published in London in 1738; and contained, as will be seen from its title, records of experiments of very much the same nature as those of Duhamel.

Jethro Tull's Theory.

Some reference may be made to a theory which created a considerable amount of interest when it was first published—viz., that of Jethro Tull. The chief value of Tull's contribution to the subject of agricultural science was, that he emphasised the importance of tillage operations by putting forward a theory to account for the fact, universally recognised, that the more thoroughly a soil was tilled, the more luxuriant the crops would be. As Tull's theory had a very considerable influence in stirring up interest in many of the most important problems in agricultural chemistry, and as it contained in itself much, the value of which we have only of late years come to understand, a brief statement of this theory may not be without interest.

According to Tull the food of plants consists of the particles of the soil. These particles, however, must be rendered very minute before they become available for the plant, which absorbs them by means of its rootlets. This pulverisation of the soil goes on in nature independently of the farmer, but only very slowly, and the farmer has therefore to hasten it on by means of tillage operations. The more efficiently these operations are carried on, the more abundant will the supply

of plant-food be rendered in the soil. He consequently introduced and advocated the system of horse-hoe husbandry. This theory, he informs us, was suggested to him by the custom, which he had noticed on the Continent, of growing vines in rows, and hoeing the intervals between these rows from time to time. The excellent results which followed this mode of cultivation induced him to adopt it in England for his farm crops. He accordingly sowed his crops in rows or ridges, wide enough apart to admit of thorough tillage of the intervals by ploughing as well as by hand-hoeing. This he continued until the plant had reached maturity. As to the exact width of the interval most suitable, he made a large number of experiments. At first, in the cultivation of wheat, he made this interval six feet wide; but latterly he adopted an interval of lesser width, that finally arrived at being between four and five feet. He likewise experimented on each separate ridge as to which was the best number of rows of wheat to be sown, latterly adopting, as most convenient, two rows at ten inches apart. The great success which he met with in this system of cultivation induced him to publish the results of his experiments in his famous work, 'Horse-Hoeing Husbandry.'

While Tull's theory was based on principles at heart thoroughly sound, he was carried away by his personal success into drawing unwarrantable deductions. Thus he came to the conclusion that rotation

of crops was unnecessary, provided that a thorough system of tillage was carried out. Manures also, according to him, might be entirely dispensed with under his system of cultivation, for the true function of all manures is to aid in the pulverisation of the soil by fermentation.

The first really valuable scientific facts contributed to the science were made by Priestley, Bonnet, Ingenhousz, and Sénébier.

Discovery of the Source of Plants' Carbon.

To Charles Bonnet (1720-1793), a Swiss naturalist, is due the credit of having made the first contribution to a discovery of very great importance—viz., the true source of the *carbon,* which we now know forms so large a portion of the plant-substance. Bonnet, who had devoted himself to the question of the function of leaves, noticed that when these were immersed in water bubbles were seen, after a time, to collect on their surface. De la Hire, it ought to be pointed out, had noticed this same fact about sixty years earlier. It was left to Priestley, however, to identify these bubbles with the gas he had a short time previously discovered—viz., oxygen. Priestley had observed, about this time, the interesting fact that plants possessed the power of purifying air vitiated by the presence of animal life.[1] The

[1] Priestley, however, did not realise that *carbonic acid gas* was a necessary plant-food; on the contrary, he considered it to have a

next step in this highly interesting and important discovery was taken by John Ingenhousz (1730-1799), an eminent physician and natural philosopher. In 1779, Ingenhousz published a work in London entitled 'Experiments on Vegetables.' In it he gives the results of some important experiments he had made on the question already investigated by Bonnet and Priestley. These experiments proved that plant-leaves only gave up their oxygen in the presence of sunlight. In 1782 he published another work on 'The Influence of the Vegetable Kingdom on the Animal Creation.'[1]

The source of the gas, which Bonnet had first noticed to be given off from plant-leaves, Priestley had identified as oxygen, and Ingenhousz had proved to be only given off under the influence of the sun's rays, was finally shown by a Swiss naturalist, Jean Sénébier[2] (1742-1809), to be the *carbonic acid gas* in the air, which the plant absorbed and decomposed, giving out the oxygen and assimilating the carbon.

deleterious action on plant-growth. Percival was really the first to point out that carbonic acid gas was a plant-food.

[1] It is recorded as an instance of the scientific enthusiasm of the man, that he was wont to carry about with him bottles containing oxygen, which he had obtained from cabbage-leaves, as also coils of iron wire, with which he could illustrate the brilliant combustion which ensued on burning the latter in oxygen gas.

[2] For a full account of Sénébier's researches, see 'Physiologie végétale, contenant une description des organes des plantes, et une exposition des phénomenes produits par leur organisation, par Jean Sénébier.' (5 tomes. Genève, 1800.)

Publication of First English Treatise on Agricultural Chemistry.

In 1795, a book dealing with the relations between chemistry and agriculture was published. This work was written by a Scottish nobleman, the Earl of Dundonald, and possesses especial interest from the fact that it is the first book in the English language on agricultural chemistry. The full title is as follows: 'A Treatise showing the Intimate Connection that subsists between Agriculture and Chemistry.'

In his introduction the author says: "The slow progress which agriculture has hitherto made as a science is to be ascribed to a want of education on the part of the cultivators of the soil, and to a want of knowledge, in such authors as have written on agriculture, of the intimate connection that subsists between the science and that of chemistry. Indeed, there is no operation or process not merely mechanical that does not depend on chemistry, which is defined to be a knowledge of the properties of bodies, and of the effects resulting from their different combinations."

In quoting this passage Professor S. W. Johnson remarks:[1] "Earl Dundonald could not fail to see that chemistry was ere long to open a splendid future for the ancient art that had always been and always will be the prime supporter of the nations. But when he

[1] How Crops Grow. By Professor S. W. Johnson. Macmillan & Co. (Introduction, p. 4.)

wrote, how feeble was the light that chemistry could throw upon the fundamental questions of agricultural science! The chemical nature of the atmosphere was then a discovery of barely twenty years' standing. The composition of water had been known but twelve years. The only account of the composition of plants that Earl Dundonald could give was the following: 'Vegetables consist of mucilaginous matter, resinous matter, matter analogous to that of animals, and some proportion of oil. . . . Besides these, vegetables contain earthy matters, formerly held in solution in the newly-taken-in juices of the growing vegetables.' To be sure, he explains by mentioning in subsequent pages that starch belongs to the mucilaginous matter, and that on analysis by fire vegetables yield soluble alkaline salts and insoluble phosphate of lime. But these salts, he held, were formed in the process of burning, their lime excepted; and the fact of their being taken from the soil and constituting the indispensable food of plants, his lordship was unacquainted with. The gist of agricultural chemistry with him was, that plants 'are composed of gases with a small proportion of calcareous matter; for although this discovery may appear to be of small moment to the practical farmer, yet it is well deserving of his attention and notice.'"

De Saussure.

The year 1804 witnessed the publication of by far the most important contribution made to the science

up till this time. This was 'Recherches Chimique sur la Végétation,' by Theodore de Saussure, one of the most illustrious agricultural chemists of the century. De Saussure was the first to draw attention to the mineral or ash constituents of the plant; and thus anticipate, to a certain extent, the subsequent famous "mineral" theory of the great Liebig. The French chemist maintained that these ash ingredients were essential; and that without them plant-life was impossible. He also adduced fresh experiments of his own in support of the theory, based on the experiments of Bonnet, Priestley, Ingenhousz, and Sénébier, that plants obtain their carbon from the carbonic acid gas in the air, under the influence of the sunlight. He was of opinion that the *hydrogen* and *oxygen* of the plant were, probably, chiefly derived from water. He showed that by far the largest portion of the plant's substance was derived from the air and from water, and that the ash portion was alone derived from the soil. To Saussure we owe the first definite statement on the different sources of the plant's food. It may be said that the lapse of nearly a century has shown his views to be, in the main, correct.

Source of Plant-nitrogen.

There was one question, which, even at that remote period in the history of the subject, engaged the attention of agricultural chemists—viz., the question of the source of the plant's *nitrogen*—a question which may

be fitly described at the present hour as still the burning question of agricultural chemistry.[1]

As soon as it was discovered that nitrogen was a constituent of the plant's substance, speculations as to its source were indulged in. The fact that the air furnished an unlimited storehouse of this valuable element, and the analogy of the absorption of carbon (from the same source by plant-leaves), naturally suggested to the minds of early inquirers that the free nitrogen of the air was the source of the plant's nitrogen. As, however, no direct experiments could be adduced to prove this theory, and as, moreover, nitrogen was found in the soil, and seemed to be a necessary ingredient of all fertile soils, the opinion that the soil was the only source gradually supplanted the older theory. Little value, however, must be attached to these early theories, as they can scarcely be said to have been based on experiments of serious value. Indeed it may be safely affirmed, in the light of subsequent experiments, that it was impossible for this question to be decided at this early period, from the fact that analytical apparatus, of a sufficiently delicate nature, was then wholly unknown. Indeed it is only within the last few years that it has been possible to carry out experiments which may be regarded as at all crucial. A short sketch of the development of our knowledge of the relation of nitrogen to the plant will be given further on.

[1] See p. 40 to 45.

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